Alternative Orbit Correction Modeling for the MAX IV 3 GeV Storage Ring

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July 24, 2013 (Revised October 9, 2014)

MAX-lab Internal Note 20130724[1]

Abstract

Previous analysis of the MAX IV 3 GeV storage ring lattice under the influence of imperfections [1] gave a somewhat pessimistic assessment of performance after orbit correction. It was, however, also pointed out that orbit correction itself was not being modeled in accordance with how the procedure is carried out in the real storage ring. It was assumed that poor post-correction performance could be related to modeling deficiencies. This note summarizes an attempt to model orbit correction in a different way so that a better representation of its real application is achieved. Resulting closed orbit deviations, dynamic aperture, and emittance coupling are presented. They show that a more optimistic outcome can be expected from orbit correction in the real storage ring.

[1] This document can be found at `http://www.maxlab.lu.se/node/999`

Introduction

In the analysis of the MAX IV 3 GeV storage ring optics [1] the standard imperfection models appeared to have a significant impact on the performance of the lattice, most notably, comparably large closed orbit deviations (CODs) after orbit correction (OCO) had been performed resulting in a significant reduction of dynamic aperture (DA) as well as emittance coupling and beam ellipse twist values beyond what was expected considering the level of imperfections.

However, as was already pointed out in the initial analysis [1], OCO as performed by TRACY-3 does not exactly match how the procedure is carried out in the real storage ring. It was quickly suspected that the lower than expected performance of the lattice under the influence of imperfections could be related to the way in which OCO was modeled in the TRACY-3 tracking studies.

Alternative Model

In an attempt to more closely model the realistic application of OCO, three significant changes were made in the model:

- The girder definitions were removed so that all magnets within the magnet blocks as well as the BPMs would be misaligned individually from the ideal orbit.
- All dipole slices forming an individual dipole were moved onto a common "girder". The individual misalignment of the slices was removed. This common "dipole girder", however, received the same misalignments as the slices previously carried (25 μm RMS transversely, 0.2 mrad RMS roll error).
- The misalignments of all magnets directly adjacent to the BPM's, i.e. the magnets to which the BPM's will be calibrated (all OXX, SDend, as well as SFi/o/m), were reduced to the level of the BPM calibration accuracy (3 μm RMS transversely, 0.2 mrad RMS roll error).

Apart from these changes, neither the lattice nor the imperfection models were changed[2] (i.e. apart from the changes described here, all parameters for imperfections listed in Sections 4.1.2 and 4.1.3 of [1] have also been applied in the studies mentioned here).

[2] One previous mistake in the random field error definitions was, however, discovered and has now been corrected. The 0.05% RMS gradient errors in all dipoles is now being correctly applied. In previous studies this had been wrongly specified leading to application of this error roughly a factor six beyond its proper specification.

The changes listed above serve two distinct purposes. Firstly, the artificial misalignments of individual slices within the dipoles are removed. It is assumed that the dipole as a whole can be misaligned, but not one slice against the other. Considering that the slices are after all artificial and that careful mapping of the dipole field in the magnet blocks will be performed, this is deemed a realistic representation. Secondly, and more importantly, the ideal orbit (to which Tracy-3 performs orbit correction) now coincides with the design orbit (defined by the centers of the calibrated BPMs) apart from BPM calibration uncertainty. In this way, Tracy-3 corrects the orbit to the same orbit as real OCO attempts to do in the actual storage ring. The ideal orbit to which Tracy-3 always corrects, is not known in the real machine, but the design orbit is and it is used for OCO. With the two now coinciding (apart from BPM calibration uncertainty), OCO is being modeled much more closely to how it is applied in the real storage ring.

While these changes ensure that OCO in simulation more accurately resembles its real application and hence, resulting lattice performance (e.g. RMS CODs or post-correction DA) should be closer to reality, this model is of course still inaccurate. It remains skewed, since it cannot take into account that alignment imperfections of magnets within the same magnet block can be correlated both as a result of machining imperfections as well as alignment inaccuracy. Therefore, this model is not suited to derive OCO requirements (e.g. pre-correction CODs, required corrector strengths, aperture requirements, etc.).

Results

Using this alternate model and applying it to 50 seeds reveals that post-correction CODs drop to $2.7\,\mu$m ($0.1\,\mu$m RMS) in the horizontal and $4.3\,\mu$m ($0.5\,\mu$m RMS) in the vertical plane. The mean corrector strengths are $19.8\,\mu$rad ($6.5\,\mu$rad RMS) in the horizontal and $24.1\,\mu$rad ($5.5\,\mu$rad RMS) in the vertical. These values are much lower than the values reported using the original model (cf. Table 7 in [1]) and the CODs are now on the level of the BPM calibration accuracy as one would expect for such a model. This is shown in Fig. 1 which can be directly compared to Fig. 21 (bottom) in [1]. Figure 2 shows histograms for CODs and can be compared to Fig. 22 (bottom) in [1]. The 20 spikes seen in the vertical CODs are the result of having 10 BPM's but only 9 vertical correctors per achromat. This also leads to an apparently larger spread of the vertical CODs compared to the horizontal.

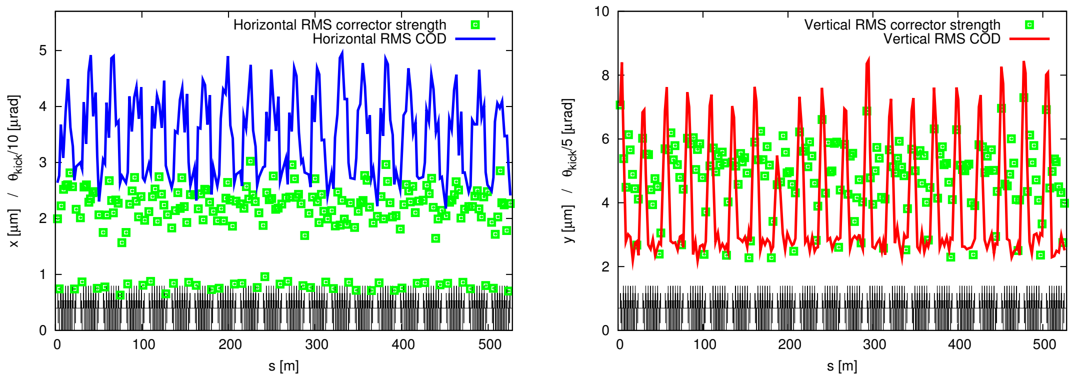

Figure 1: RMS closed orbit deviations (at the BPM's) after orbit correction and required RMS corrector strengths for 50 error seeds in the MAX IV 3 GeV storage ring using an alternate misalignment model.

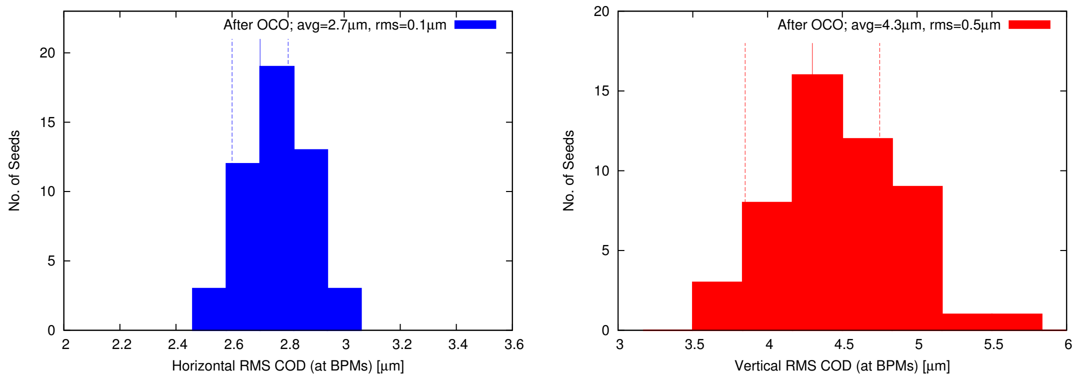

Figure 2: Histogram of RMS closed orbit deviations after orbit correction for 50 error seeds in the MAX IV 3 GeV storage ring using an alternate misalignment model. The mean values and standard deviations are indicated.

The average emittance coupling is 0.43% (0.32% RMS) and the beam ellipse twist in the long straights is 0.9° RMS (cf. Fig. 3, compare to Fig. 23 (bottom) in [1]). The average of the RMS beta beat (across 20 seeds) reduces to 1.2% (H) and 2.4% (V).

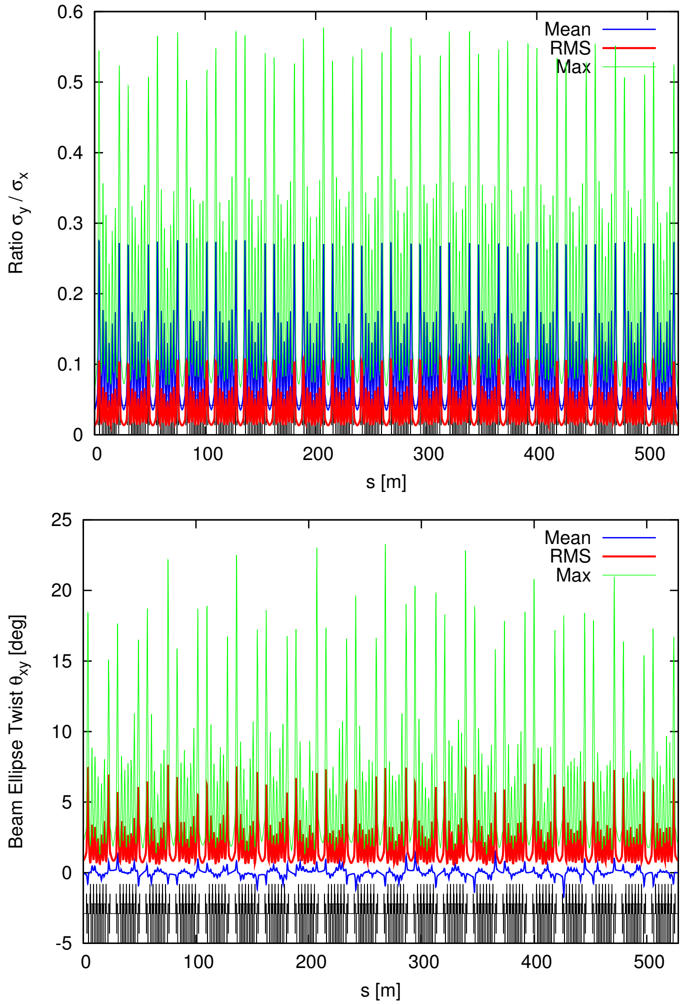

Figure 3: Transverse beam size aspect ratio (left) and beam ellipse twist (right) after orbit correction for 50 error seeds in the MAX IV 3 GeV storage ring using an alternate misalignment model.

Finally, all of this is also reflected by the improved DA displayed in Fig. 4. It can be directly compared to the DA shown in [1] as Fig. 14.

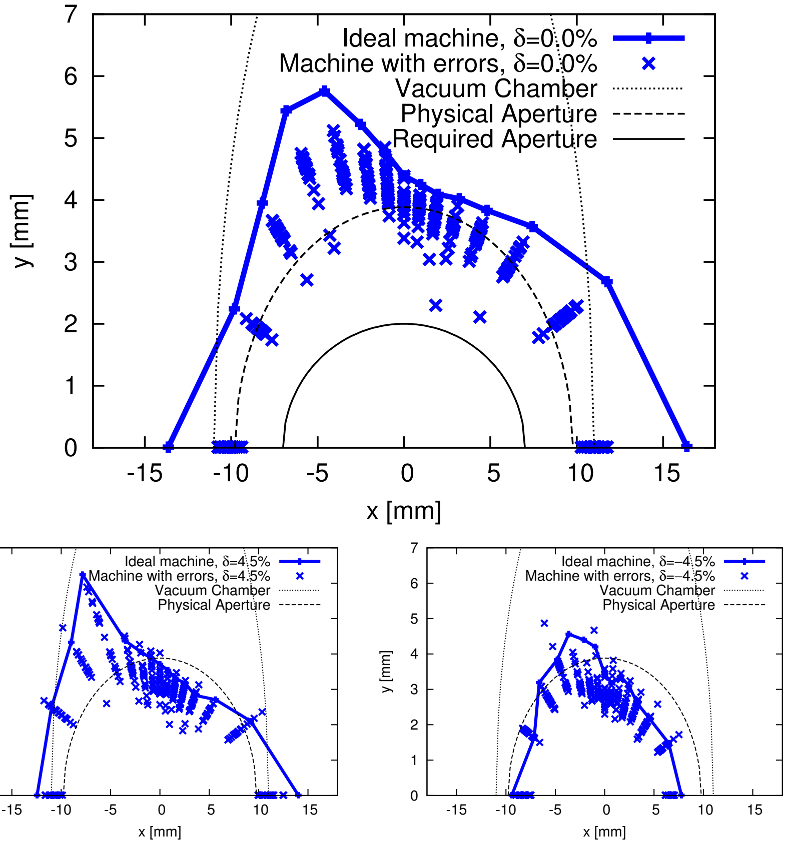

Figure 4: Dynamic aperture at the center of the long straight section in the MAX IV 3 GeV storage ring (bare lattice) from tracking with Tracy-3. The plots show the ideal lattice and results for 20 seeds with field, multipole, and alignment errors. An alternate misalignment model has been chosen here.

Conclusions

Considering that beam-based girder re-alignment can be employed to minimize mean corrector strengths within magnet blocks thus ensuring the block is actually aligned well to the ideal orbit, this model should generate results that match the post-commissioning situation fairly well. For such a longer-term perspective, the previous study [1] delivered a systematically pessimistic assessment of lattice performance under the influence of imperfections. However, the results presented in [1] for the early commissioning scenario along with the derived requirements for OCO should remain valid.

References

[1] MAX-lab Internal Note 20121107, available at http://www.maxlab.lu.se/node/999